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# **The Curtain Effect in a Shallow Water Environment**

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## **PREFACE**

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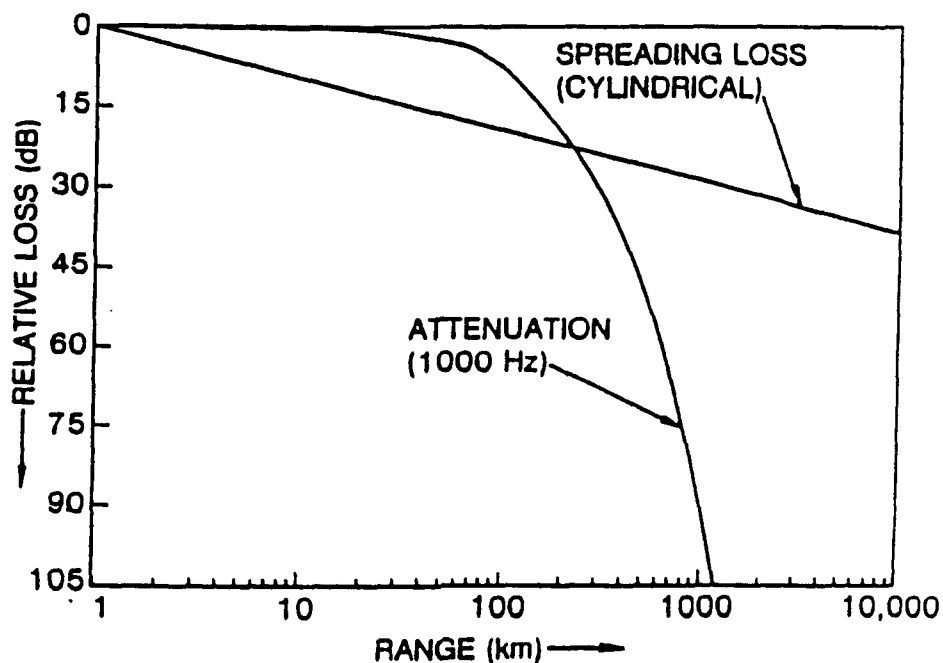
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13. ABSTRACT (Maximum 200 words)  The curtain effect that controls sound propagation in a sound channel (Browning, et al., J. Acoust. Soc. Am. Suppl. 1 88, S132 [1990]) is shown to exist in modified form for severely bottom-limited propagation conditions that can exist in shallow water during the summer. The initially dominant loss component, whose rate decreases with range, is now angular-dependent multiple bottom bounce propagation loss. The range-independent component is an effective attenuation that includes low-angle bottom loss. The transition between these components is equivalent to the crossover of the components in the sound channel case. An effective range can be obtained by extending the effective attenuation component back to the intersection with the rate of spreading loss component. Illustrations are given for several shallow water areas.				
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# THE CURTAIN EFFECT IN A SHALLOW ENVIRONMENT



## ATTENUATION vs. SPREADING LOSS



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Figure 1. Attenuation vs. Spreading Loss

The application of the curtain effect (ref. 1, 2) has allowed a simple estimation of the relative range of propagation that can be obtained for various frequencies in a sound channel where the principal loss mechanisms will be spreading loss and attenuation.

It is based on the concept (illustrated here at 1000 Hz) that spreading loss increases linearly with the logarithm of range, while attenuation loss increases linearly with range. Although spreading loss is initially high, as the range increases, attenuation will become the dominant factor; ultimately its rapid increase creates a "curtain" that limits the practical range of propagation.

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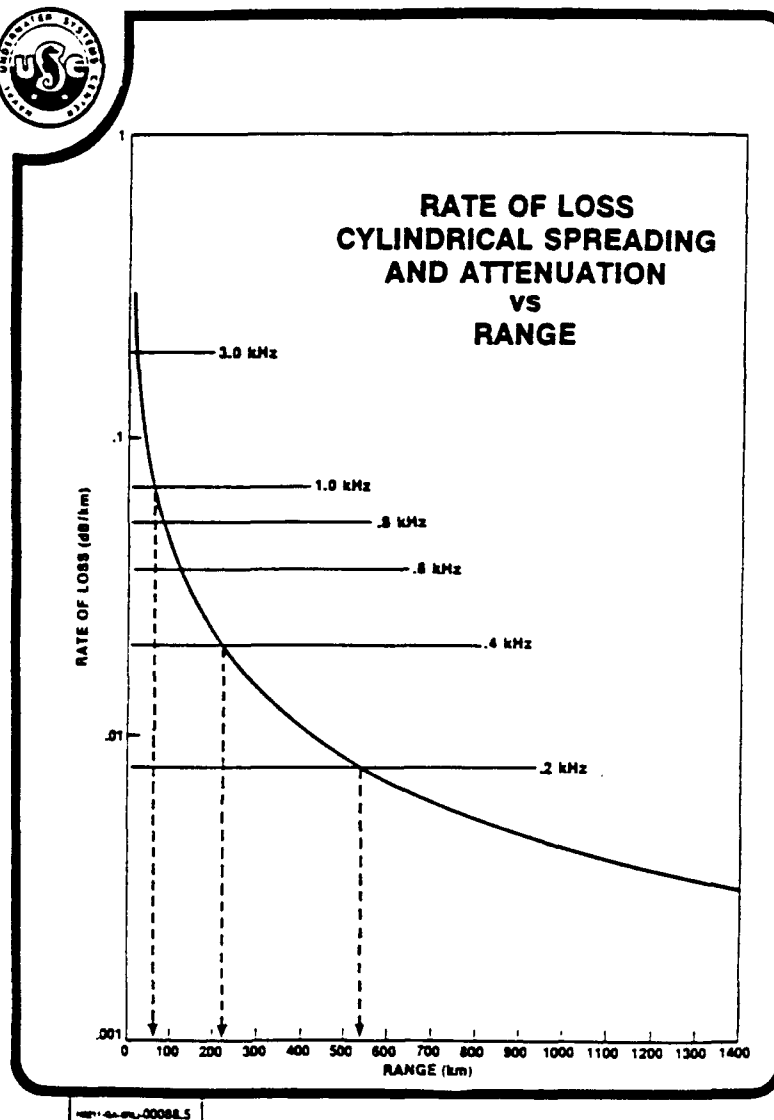


Figure 2. Rate of Loss vs. Range

The concept of the curtain effect can be presented in various ways; each gives a different perspective on the limitations on propagation.

A comparison of the propagation loss components was given in figure 1. In figure 2, the rates of loss for the two components are compared. The attenuation coefficient (a rate of loss) is constant with range for a given frequency, and the rate of spreading loss decreases with range.

Here is the power of this simple analysis: you can easily visualize that, below 200 Hz, we have a long range world, and, above 1000 Hz, the ranges rapidly shorten. For example, at 200 Hz, sound energy can propagate out to 540 km before attenuation loss exceeds the rate of spreading loss, and, at 1000 Hz, the cross-over range decreases to 80 km.



In the M-S model, the propagation loss is thus represented in terms of sea state (wave height), bottom type (or bottom loss, if known), water depth, frequency, and the depth of the positive-gradient layer. The skip distance is used as a reference to define regions where wave-front spreading follows square, three-halves, and first-power laws as a function of range.

For long ranges,  $R \geq 8H$ ,

$$N = 10 \log R + \left[ aR + a_r \left( \frac{R}{H} - 1 \right) \right] + 10 \log H + 64.5 - k_L \text{ dB.}$$

Figure 3. Marsh-Schulkin Shallow Water Model

With the renewed interest in shallow water propagation, we were interested in determining whether the curtain concept could be applied to propagation conditions where there are multiple boundary interactions. The Navy standard shallow water model now in use is the Marsh-Schulkin model (ref. 3) developed in the 1960s from the extensive Colossus data base. For other than short ranges, this model lumps boundary interactions together with the volume attenuation to form an effective attenuation. These terms are outlined by the dashed line in figure 3. Hence, we have the proper ingredients for a curtain effect analysis: spreading loss and an effective attenuation. It should be noted that Cole has previously shown (ref. 4) limitations in ascribing too detailed a physical interpretation to the cycle range and bottom loss parameters used in the M-S model.

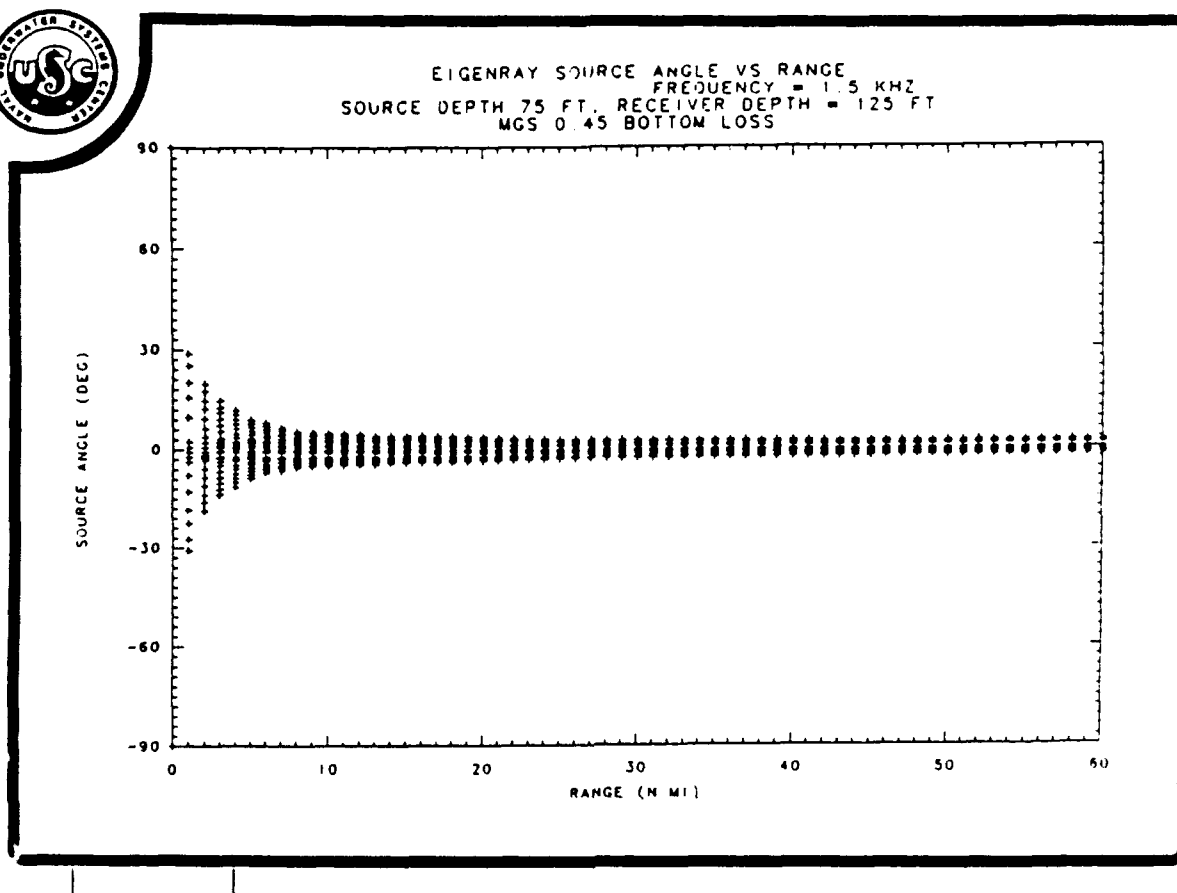


Figure 4. Shallow Water Eigenrays

We thought it would be worthwhile to use some of the modern modelling techniques to examine general features of the Marsh-Schulkin model that influence the curtain effect. Here we have a plot of eigenray source angle vs. range for a typical shallow water location. At ranges greater than 10 nmi all the higher angle rays are gone, resulting in relatively stable low angle propagation conditions which were reported in ref. 5 and which are very similar to that found in sound channels. This result, of course, shows just the angular stripping and does not directly indicate the magnitude of the energy stripping.

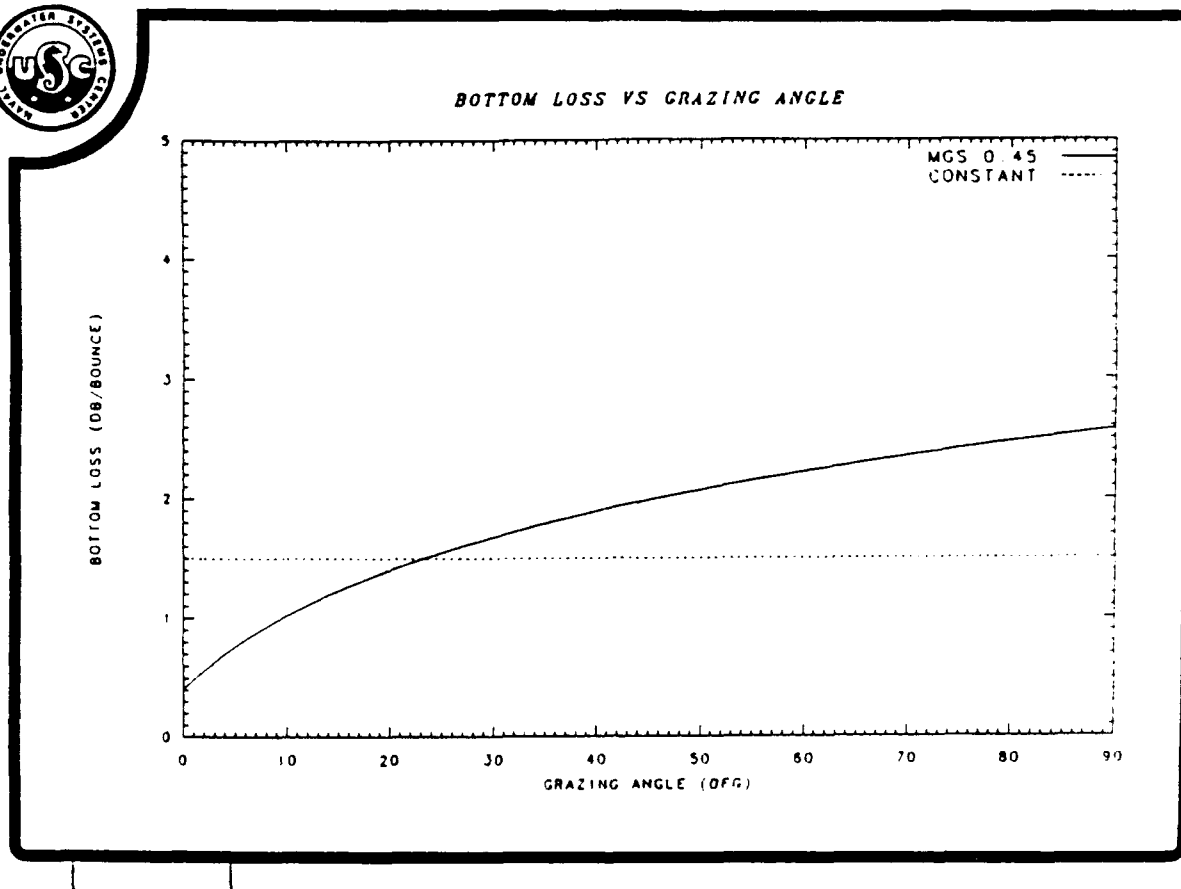


Figure 5. Bottom Loss Comparison

We carried this analysis one step further to determine the cause of the high angle extinction. In the first case we showed, an MSG type bottom loss (ref. 6) was used so the higher angles had a higher loss per bounce. We now repeated the analysis with a constant bottom loss to see if there would be any significant difference.



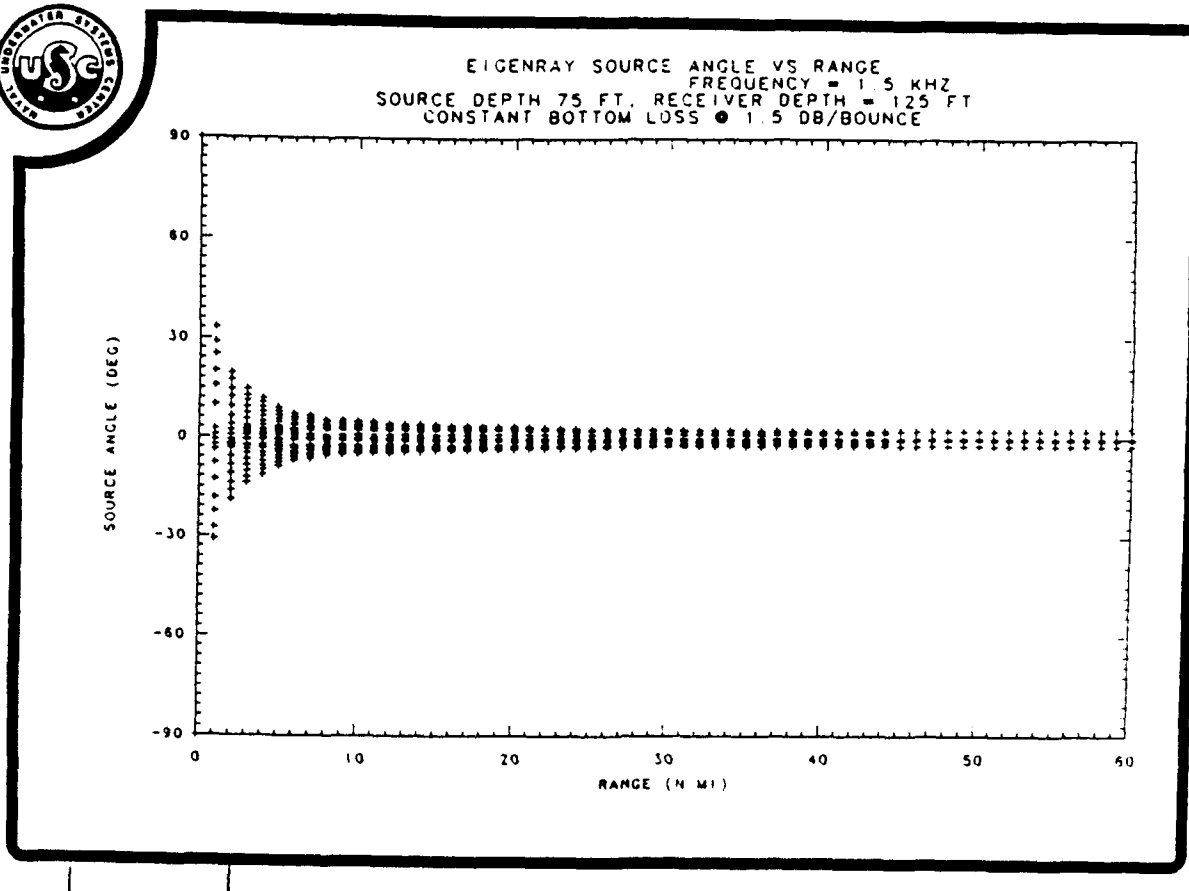


Figure 6. Shallow Water Eigenrays 2

The results are remarkably similar which indicates that geometry is the controlling factor. For this comparison, it is the number of bounces rather than the loss per bounce that is the cause of the stripping at higher angles. This is not to say that if the bottom loss has a strong angular dependence, increased bottom loss at higher angles may be the principal reason for more pronounced stripping (ref. 5).



# SHALLOW WATER PROPAGATION LOSS vs RANGE Based on Marsh-Schulkin Eq (1962)

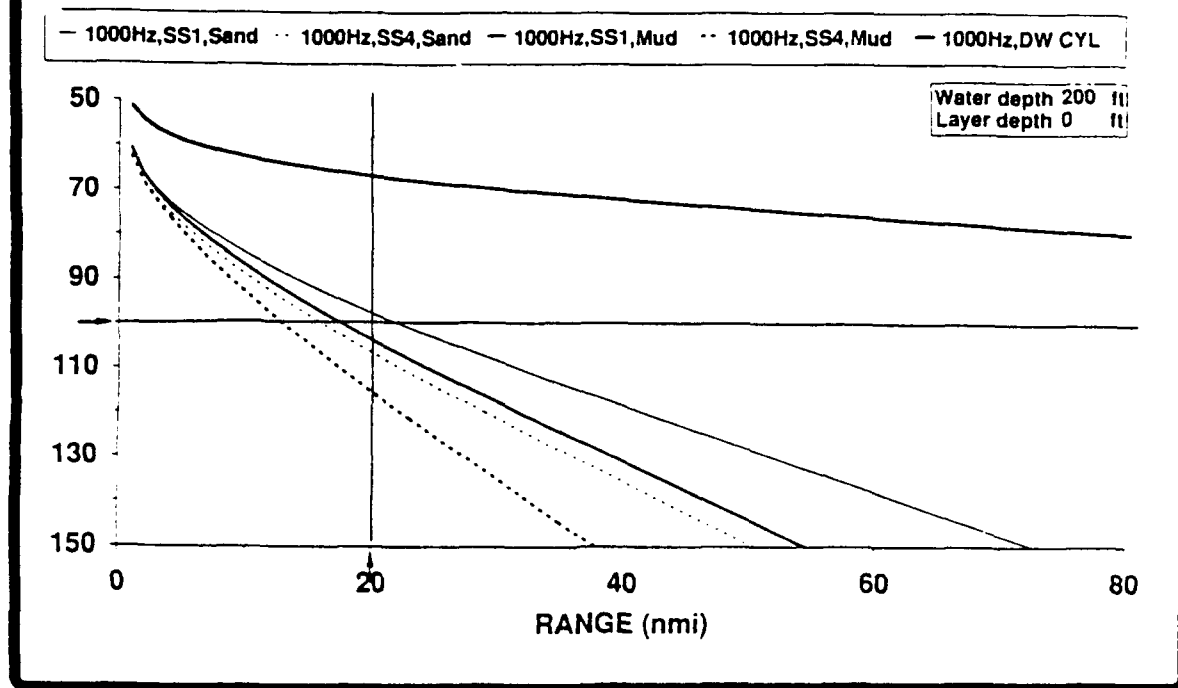


Figure 7. Marsh-Schulkin Results -- 1000 Hz

We have taken a practical approach to first express this shallow water curtain. Using the Marsh-Schulkin predictions, we determine the range obtainable as a function of frequency for the realistic threshold level of 100 dB (one-way transmission loss). Marsh-Schulkin allows two bottom types (mud and sand), and we have chosen two sea states (1 and 4). For these cases, we have chosen a layer depth of 0 ft, which corresponds to no duct, and, for the soundspeed profile used, will result in downward refraction. It also should be noted that the Marsh-Schulkin model is not dependent on depth of either source or receiver. The resulting four propagation loss curves are shown here for 1000 Hz. The threshold level (100 dB propagation loss) and a particular range (20 nmi) are shown for reference. Sighting along the reference range line allows one to get a feeling for the relative loss due to each component at that range.



# SHALLOW WATER PROPAGATION LOSS vs RANGE Based on Marsh-Schulkin Eq (1962)

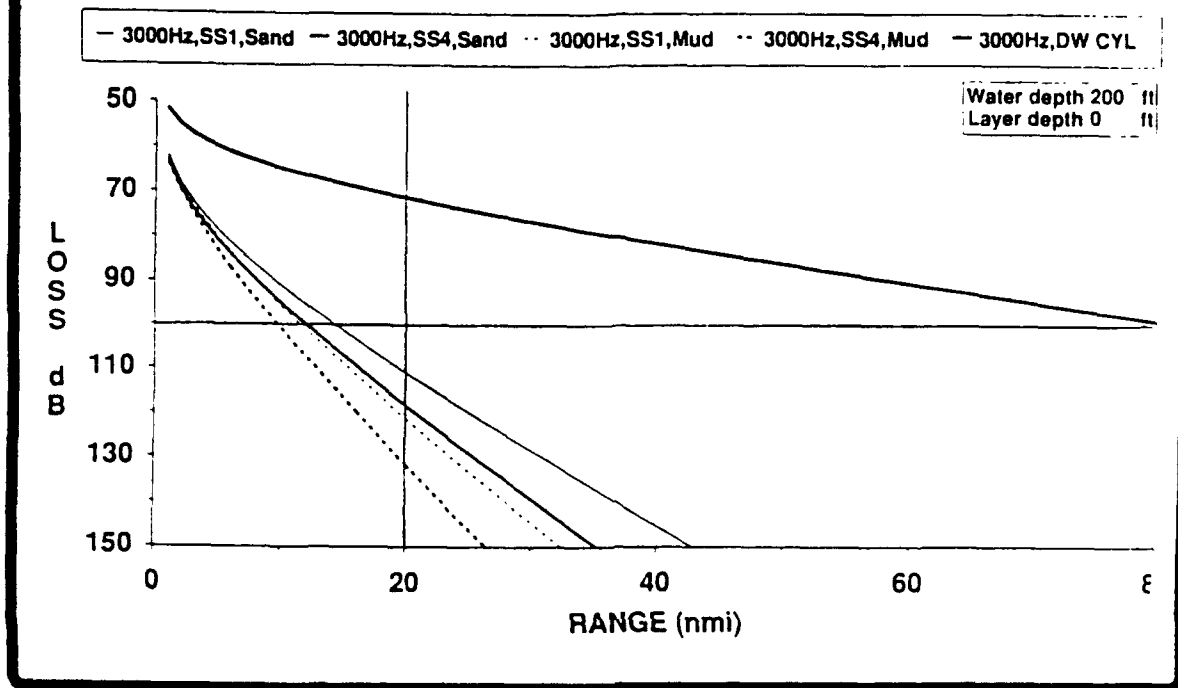


Figure 8. Marsh-Schulkin Results -- 3000 Hz

The Marsh-Schulkin loss curves are now shown for 3000 Hz. As might be expected from seawater attenuation alone, the range to the threshold is less, but note that the loss due to the boundary interactions (surface and bottom) has increased also. So at higher frequencies you have a double dilemma; first, generally less signal is available, and second, a given amount of loss corresponds to a smaller change in environmental conditions. For example, a change from sea state 1 to sea state 4 at 3000 Hz and a range of 20 nmi results in a 10 dB increase in loss; at 125 Hz, (figure 9) the increase would be negligible. Hence, if one had a given amount of signal excess available, at low frequencies this could compensate for a large change in the environmental conditions, such as sea state, but at the higher frequencies, it could cover only a more limited range.



# SHALLOW WATER PROPAGATION LOSS vs RANGE Based on Marsh-Shulkin Eq (1962)

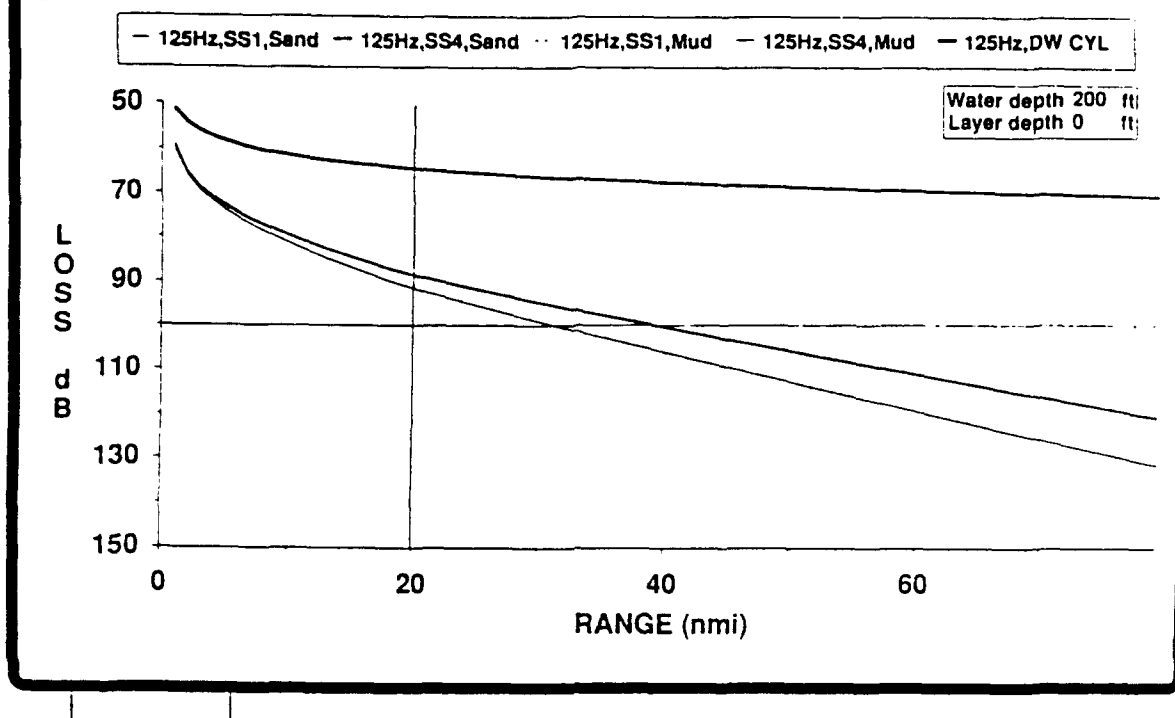


Figure 9. Marsh-Schulkin Results -- 125 Hz

Conversely, here are the same curves for 125 Hz. The range to the threshold has greatly increased, and the relative loss due to environmental factors (especially, sea state) has greatly decreased. We now take these results for various frequencies and develop certain curves.

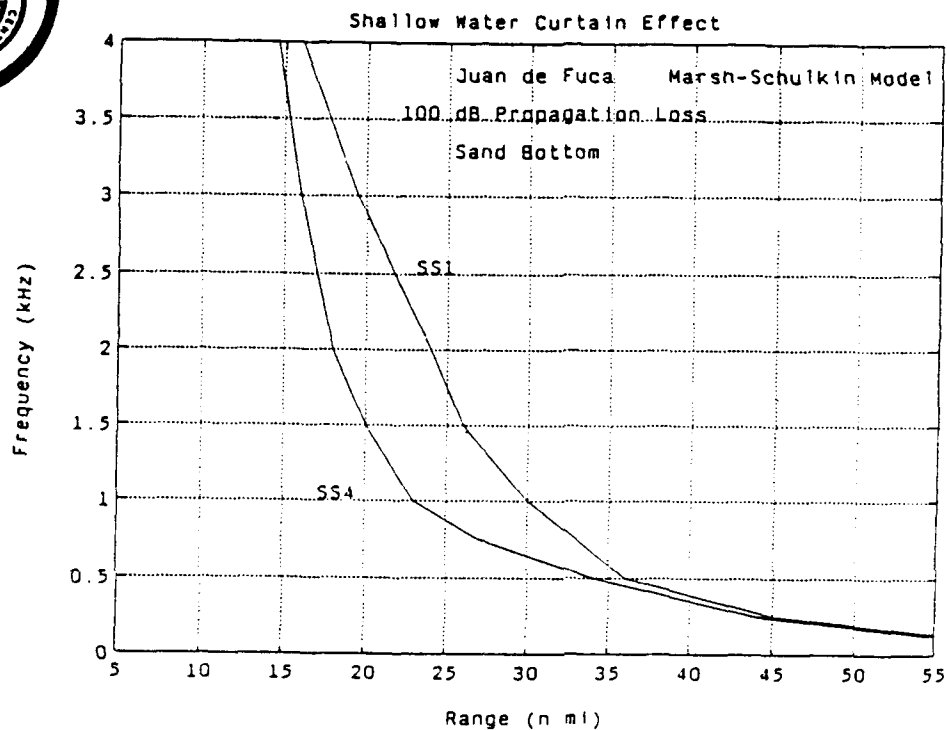


Figure 10. Shallow Water Curtain: Marsh-Schulkin 1

The shallow-water curtain effect is first shown for the Marsh-Schulkin model with a sand bottom. Two cases are presented: sea states 1 and 4. You can see a relative increase in range below 1500 Hz and also a reduction in the relative impact of a change in sea state. For a given sea state, shifting from 1500 to 4000 Hz results in a range change of 6-7 nmi, roughly the same as that caused by the change from sea state 1 to 4 at a given frequency in this band.

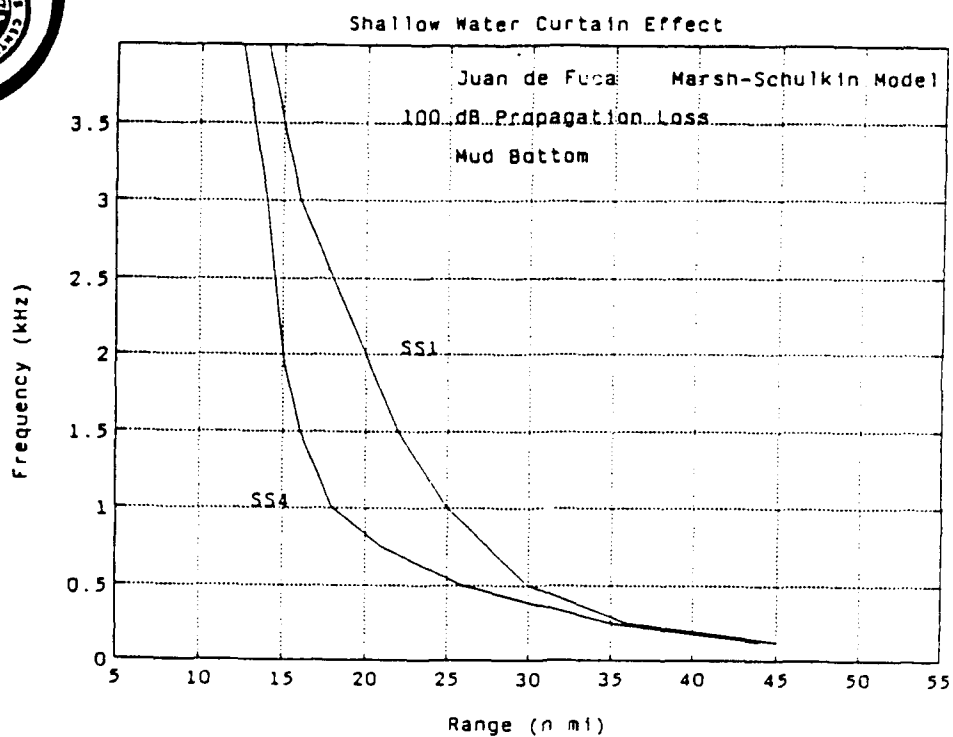


Figure 11. Shallow Water Curtain: Marsh-Schulkin 2

For the mud bottom cases, the curtain occurs even more rapidly, as might be expected. For both bottom types, the greatest range impact due to sea state appears to be in the 1000 to 2000 Hz region.

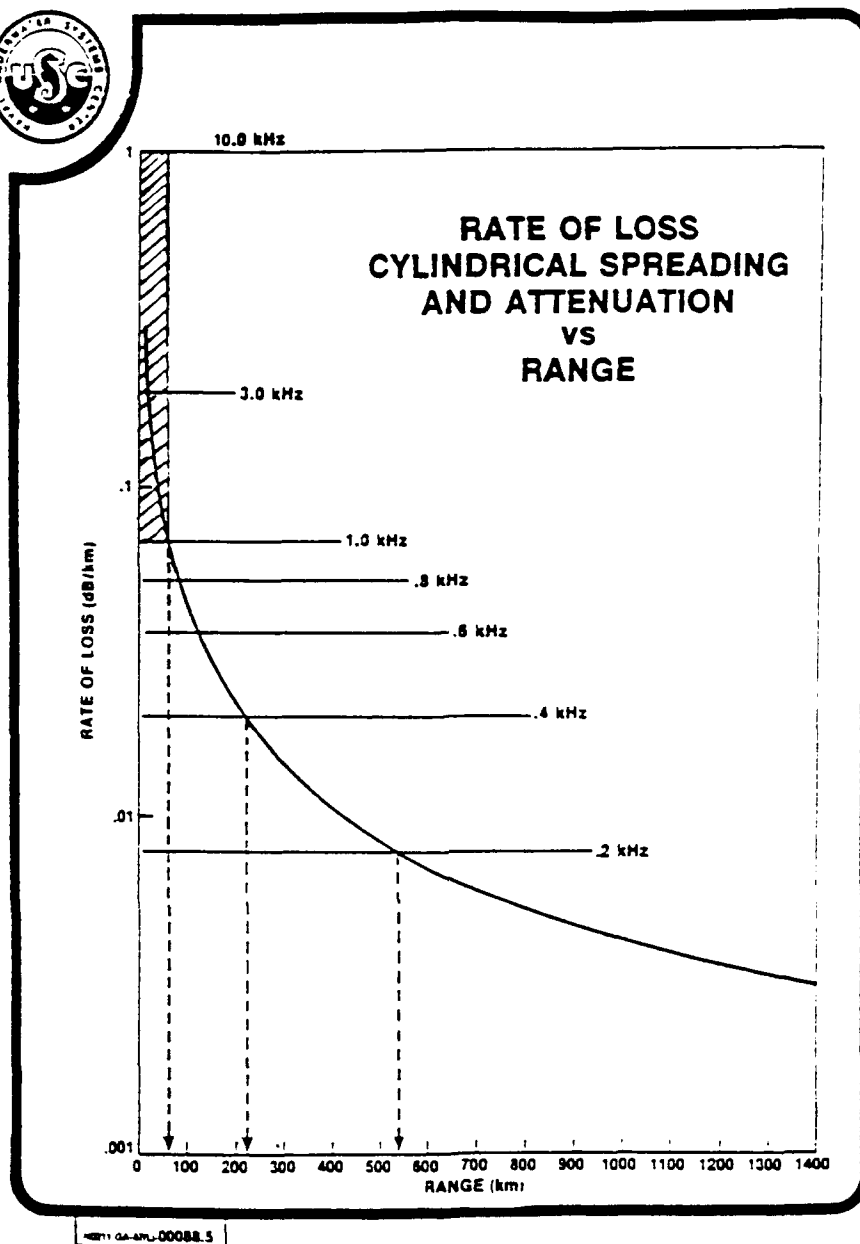


Figure 12. Shallow Water Curtain: Rate of Loss

To express the shallow water curtain in another way, we examined some of the 1960s reports where Marsh-Schulkin effective attenuation coefficients were computed for various shallow water locations. At approximately 1000 Hz, we found roughly an order of magnitude variation in the reported attenuation values shown by the hatched areas. As shown here, such a variation would mean that, under the poorest conditions, a 1000 Hz system would act like a 10,000 Hz system under good conditions.



### Cut-off Frequency for Surface Duct Energy Trapping

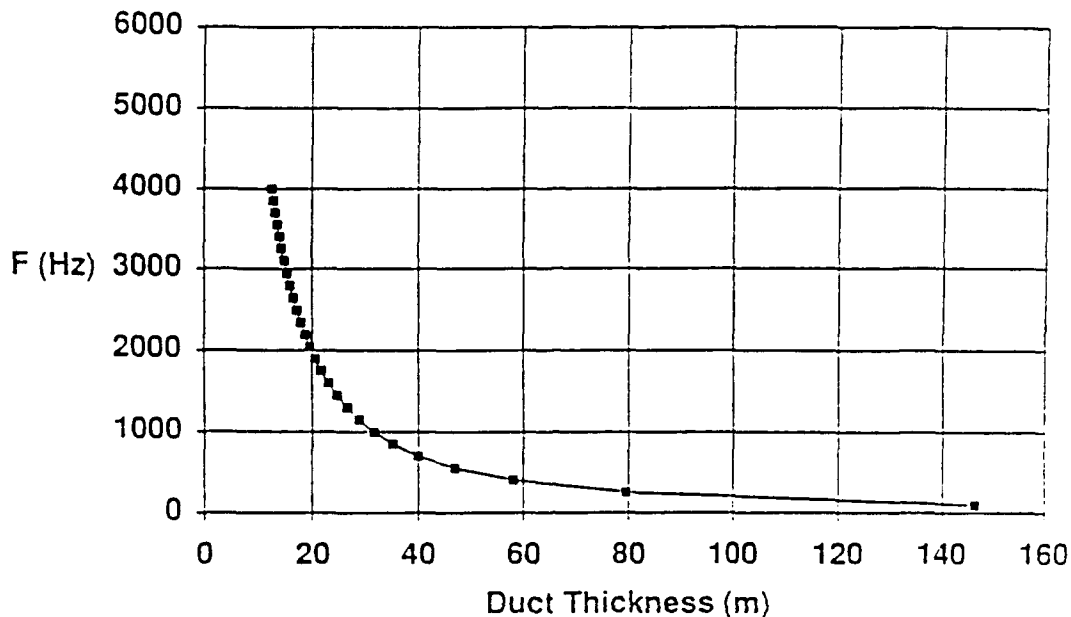


Figure 13. Channel Cutoff "Reverse Curtain"

For completeness we also should mention, since ducting is probably more prevalent in shallow water than in strongly downward refracting conditions (see ref. 7), the possibility of a "reverse curtain effect" exists for these cases. In a duct, as the frequency is lowered we reach a cutoff frequency where the acoustic energy is no longer trapped in the duct. If the energy is not trapped in a duct, interaction with the bottom could take place and greater propagation loss would result. This can produce a reverse curtain, that is, a propagation limit is reached by going down, rather than up, in frequency. Propagation in ducts, therefore, can be bounded between two effects, and the result is a commonly found optimum propagation frequency. Examples of this, as well as a more comprehensive analysis of shallow water propagation at various locations, is given in a companion paper by Monti et al. (ref. 7).





## THE CURTAIN EFFECT IN SHALLOW WATER ENVIRONMENTS

### CONCLUSIONS

1. AS MARSH AND SCHULKIN HAVE SHOWN, SHALLOW WATER PROPAGATION CAN BE APPROXIMATED BY AN INCREASED EFFECTIVE ATTENUATION.
2. THIS RESULTS IN AN ENHANCED CURTAIN EFFECT WHICH CAN ONSET AT LOWER FREQUENCIES AND SHORTER RANGES THAN IN DEEP WATER.
3. THE ENVELOPE OF LOSS IS COMPLEX DUE TO THE DEPENDENCIES OF VARIOUS ENVIRONMENTAL FACTORS.

Figure 14.

In conclusion, first, as Marsh and Schulkin have shown, even downward refracting shallow water conditions can be approximated by an increased effective attenuation.

Second, this increased effective attenuation results in an enhanced curtain effect that can onset at lower frequencies and shorter ranges than in deep water.

Finally, the envelope of signal excess as a function of frequency is complex due to varying dependencies of several environmental factors. In general, at a given range, there is less signal available at higher frequencies because of increased attenuation, and, unfortunately, at the same time, the environmental losses for a given condition (for example, sea state 4) also increase with frequency.

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